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PHILOSOPHICAL
TRANSACTIONS.

XIV. *New Experiments upon Heat.* By Colonel Sir Benjamin Thompson, Knt. F. R. S. In a Letter to Sir Joseph Banks, Bart. P. R. S.

Read March 9, 1786.

DEAR SIR,

I HAVE at length begun the course of experiments upon heat which I have so long had in contemplation; and I have already made a discovery, which, if not new to you, is perfectly so to me, and which I think may lead to a further knowledge respecting the nature of heat.

VOL. LXXVI.

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Examining

Examining the conducting power of air, and of various other fluid and solid bodies, with regard to heat, I was led to examine the conducting power of the *Torricellian vacuum*. From the striking analogy between the electric fluid and heat respecting their conductors and non-conductors (having found that bodies, in general, which are conductors of the electric fluid, are likewise good conductors of heat, and, on the contrary, that electric bodies, or such as are bad conductors of the electric fluid, are likewise bad conductors of heat), I was led to imagine that the Torricellian vacuum, which is known to afford so ready a passage to the electric fluid, would also have afforded a ready passage to heat.

The common experiments of heating and cooling bodies under the receiver of an air-pump I concluded inadequate to determining this question; not only on account of the impossibility of making a perfect void of air by means of the pump; but also on account of the moist vapour, which exhaling from the wet leather and the oil used in the machine, expands under the receiver, and fills it with a watery fluid, which, though extremely rare, is yet capable of conducting a great deal of heat: I had recourse therefore to other contrivances.

I took a thermometer, unfilled, the diameter of whose bulb (which was globular) was just half an inch, Paris measure, and fixed it in the center of a hollow glass ball of the diameter of $1\frac{1}{4}$ Paris inch, in such a manner, that the short neck or opening of the ball being foldered fast to the tube of the thermometer $7\frac{1}{2}$ lines above its bulb, the bulb of the thermometer remained fixed in the center of the ball, and consequently was cut off from all communication with the external air. In the bottom of the glass ball was fixed a small hollow tube or point, which projecting outwards was foldered to

to the end of a common barometer tube about 32 inches in length, and by means of this opening the space between the internal surface of the glass ball and the bulb of the thermometer was filled with hot mercury, which had been previously freed of air and moisture by boiling. The ball, and also the barometrical tube attached to it, being filled with mercury, the tube was carefully inverted, and its open end placed in a bowl in which there was a quantity of mercury. The instrument now became a barometer, and the mercury descending from the ball (which was now uppermost) left the space surrounding the bulb of the thermometer free of air. The mercury having totally quitted the glass ball, and having sunk in the tube to the height of 28 inches (being the height of the mercury in the common barometer at that time), with a lamp and a blow-pipe I melted the tube together, or sealed it hermetically, about three-quarters of an inch below the ball, and cutting it at this place with a fine file, I separated the ball from the long barometrical tube. The thermometer being afterwards filled with mercury in the common way, I now possessed a thermometer whose bulb was confined in the center of a *Torricellian vacuum*, and which served at the same time as the body to be heated, and as the instrument for measuring the heat communicated.

Experiment N^o 1.

With this instrument (see fig. 1. Tab. VI.) I made the following experiment. Having plunged it into a vessel filled with water, warm to the 18th degree of REAUMUR's scale, and suffered it to remain there till it had acquired the temperature of the water, that is

to say, till the mercury in the inclosed thermometer stood at 18° , I took it out of this vessel and plunged it suddenly into a vessel of boiling water, and holding it in the water (which was kept constantly boiling) by the end of the tube, in such a manner that the glass ball, in the center of which was the bulb of the thermometer, was just submerged, I observed the number of degrees to which the mercury in the thermometer had arisen at different periods of time, counted from the moment of its immersion. Thus, after it had remained in the boiling water 1 min. 30 sec. I found the mercury had risen from 18° to 27° . After 4 minutes had elapsed, it had risen to $44^{\circ}_{\frac{1}{16}}$; and at the end of 5 minutes it had risen to $48^{\circ}_{\frac{1}{16}}$.

Experiment N^o 2.

Taking it now out of the boiling water I suffered it to cool gradually in the air, and after it had acquired the temperature of the atmosphere, which was that of 15° R. (the weather being perfectly fine), I broke off a little piece from the point of the small tube which remained at the bottom of the glass ball, where it had been hermetically sealed, and of course the atmospheric air rushed immediately into the ball. The ball surrounding the bulb of the thermometer being now filled with air (instead of being emptied of air, as it was in the before-mentioned experiment), I re-sealed the end of the small tube at the bottom of the glass ball hermetically, and by that means cut off all communication between the air confined in the ball and the external air; and with the instrument so prepared I repeated the experiment before-mentioned; that is to say, I put it into water warmed to 18° , and when it had acquired the temperature

perature of the water, I plunged it into boiling water, and observed the times of the ascent of the mercury in the thermometer. They were as follows :-

	Time elapsed.	Heat acquired.
Heat at the moment of being plunged into the boiling water,		18° R.
After having remained in the boiling water	M.-S.	°.
	0 45	27
	1 0	34 $\frac{1}{10}$
	2 10	44 $\frac{9}{10}$
	2 40	48 $\frac{2}{10}$
	4 0	56 $\frac{2}{10}$
	5 0	60 $\frac{9}{10}$

From the result of these experiments it appears evidently, that the Torricellian vacuum, which affords so ready a passage to the electric fluid, so far from being a good conductor of heat, is a much worse one than common air, which of itself is reckoned among the worst: for in the last experiment, when the bulb of the thermometer was surrounded with air, and the instrument was plunged into boiling water, the mercury rose from 18° to 27° in 45 seconds; but in the former experiment, when it was surrounded by a Torricellian vacuum, it required to remain in the boiling water 1 minute 30 seconds = 90 seconds, to acquire that degree of heat. In the vacuum it required 5 minutes to rise to 48 $\frac{2}{10}$; but in air it rose to that height in 2 minutes 40 seconds; and the proportion of the times in the other observations is nearly the same, as will appear by the following table.

		The bulb of the thermometer placed in the center of the glass ball, and			
		furrounded by a Torricellian vacuum.		furrounded by air.	
		(Exp. N° 1.)		(Exp. N° 2.)	
		Time elapsed.	Heat acquired.	Time elapsed.	Heat acquired.
Upon being plunged into boiling water			18°		18°
		M. S.	.	M. S.	.
After remaining in it		1 30	27	0 45	27
		—	—	1 0	30 $\frac{4}{10}$
		4 0	44 $\frac{9}{10}$	2 10	44 $\frac{9}{10}$
		5 0	48 $\frac{2}{10}$	2 40	48 $\frac{2}{10}$
		—	—	4 0	56 $\frac{2}{10}$
		—	—	5 0	60 $\frac{9}{10}$

These experiments were made at Mannheim, upon the first day of July last, in the presence of Professor HEMMER, of the Electoral Academy of Sciences of Mannheim, and CHARLES ARTARIA, Meteorological Instrument-maker to the Academy, by whom I was assisted.

Finding the construction of the instrument made use of in these experiments attended with much trouble and risk, on account of the difficulty of folding the glass ball to the tube of the thermometer without at the same time either closing up, or otherwise injuring, the bore of the tube, I had recourse to another contrivance much more commodious, and much easier in the execution.

At the end of a glass tube or cylinder ten or eleven inches in length, and near three-quarters of an inch in diameter internally, I caused a hollow globe to be blown $1\frac{1}{2}$ inch in diameter,

meter, with an opening in the bottom of it corresponding with the bore of the tube, and equal to it in diameter, leaving to the opening a neck or short tube, about an inch or three-quarters of an inch in length. Having a thermometer prepared, whose bulb was just half an inch in diameter, and whose freezing point fell at about $2\frac{1}{4}$ inches above its bulb, I graduated its tube according to REAUMUR's scale, beginning at 0° , and marking that point, and also every tenth degree above it to 80° , with threads of fine silk bound round it, which being moistened with lac varnish adhered firmly to the tube. This thermometer I introduced into the glass cylinder and globe just described, by the opening in the bottom of the globe, having first choaked the cylinder at about 2 inches from its junction with the globe by heating it, and crowding its sides inwards towards its axis, leaving only an opening sufficient to admit the tube of the thermometer. The thermometer being introduced into the cylinder in such a manner that the center of its bulb coincided with the center of the globe, I marked a place in the cylinder, about three-quarters of an inch above the 80th degree or boiling point upon the tube of the inclosed thermometer, and taking out the thermometer, I choaked the cylinder again in this place. Introducing now the thermometer for the last time, I closed the opening at the bottom of the globe at the lamp, taking care, before I brought it to the fire, to turn the cylinder upside down, and to let the bulb of the thermometer fall into the cylinder till it rested upon the lower choak in the cylinder. By this means the bulb of the thermometer was removed more than 3 inches from the flame of the lamp. The opening at the bottom of the globe being now closed, and the bulb of the thermometer being suffered to return into the globe, the end of the cylinder was cut off to

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within

within about half an inch of the upper choak. This being done, it is plain, that the tube of the thermometer projected beyond the end of the cylinder. Taking hold of the end of the tube, I placed the bulb of the thermometer as nearly as possible in the center of the globe, and observing and marking a point in the tube immediately above the upper choak of the cylinder, I turned the cylinder upside down, and suffering the bulb of the thermometer to enter the cylinder, and rest upon the first or lower choak (by which means the end of the tube of the thermometer came further out of the cylinder), the end of the tube was cut off at the mark just mentioned (having first taken care to melt the internal cavity or bore of the tube together at that place), and a small solid ball of glass, a little larger than the internal diameter or opening of the choak, was soldered to the end of the tube, forming a little button or knob, which resting upon the upper choak of the cylinder, served to suspend the thermometer in such a manner that the center of its bulb coincided with the center of the globe in which it was shut up. The end of the cylinder above the upper choak being now heated and drawn out to a point, or rather being formed into the figure of the frustum of a hollow cone, the end of it was soldered to the end of a barometrical tube, by the help of which the cavity of the cylinder and globe containing the thermometer was completely voided of air with mercury; when, the end of the cylinder being hermetically sealed, the barometrical tube was detached from it with a file, and the thermometer was left completely shut up in a Torricellian vacuum, the center of the bulb of the thermometer being confined in the center of the glass globe, without touching it in any part, by means of the two choaks in the cylinder, and the button upon the end of the tube.

Of these instruments I provided myself with two, as nearly as possible of the same dimensions; the one, which I shall call N° 1. being voided of air, in the manner above described; the other, N° 2. being filled with air, and hermetically sealed.

With these two instruments (see fig. 2.) I made the following experiments upon the 11th of July last, at Manheim, between the hours of ten and twelve, the weather being very fine and clear, the mercury in the barometer standing at 27 inches 11 lines, REAUMUR's thermometer at 15°, and the quill hygrometer of the Academy of Manheim at 47°.

Experiments N° 3, 4, 5 and 6.

Putting both the instruments into melting ice, I let them remain there till the mercury in the inclosed thermometers rested at the point 0°, that is to say, till they had acquired exactly the temperature of freezing water or melting ice; and then taking them out of the ice I plunged them suddenly into a large vessel of boiling water, and observed the time required for the mercury to rise in the thermometers from ten degrees to ten degrees, from 0° to 80°, taking care to keep the water constantly boiling during the whole of this time, and taking care also to keep the instruments immersed to the same depth, that is to say, just so deep that the point 0° of the inclosed thermometer was even with the surface of the water.

These experiments I repeated twice, with the utmost care; and the following table gives the result of them.

Thermometer N ^o 1.			Thermometer N ^o 2.		
Its bulb half an inch in diameter, shut up in the center of a hollow glass globe, 1½ inch in diameter, void of air, and hermetically sealed.			Its bulb half an inch in diameter, shut up in the center of a hollow glass globe, 1½ inch in diameter, filled with air, and hermetically sealed.		
Taken out of freezing water, and plunged into boiling water.			Taken out of freezing water, and plunged into boiling water.		
Time elapsed.		Heat acquired.	Time elapsed.		Heat acquired.
Exp. N ^o 3.	Exp. N ^o 4.		Exp. N ^o 5.	Exp. N ^o 6.	
M. S.	M. S.	°	M. S.	M. S.	°
0 51	0 51	10	0 50	0 30	10
0 59	0 59	20	0 35	0 37	20
1 1	1 2	30	0 41	0 41	30
1 18	1 22	40	0 49	0 53	40
1 24	1 23	50	1 1	0 59	50
2 0	1 51	60	1 24	1 20	60
3 30	3 6	70	2 45	2 25	70
11 41	10 27	80	9 10	9 38	80
22 44	21 1	= total time of heating from 0° to 80°.	16 55	17 3	= total time of heating from 0° to 80°.
Total time from 0° to 70°:			Total time from 0° to 70°:		
M. S.			M. S.		
In Exp. N ^o 3. = 11 3			In Exp. N ^o 5. = 7 45		
In Exp. N ^o 4. = 10 34			In Exp. N ^o 6. = 7 25		
Medium = 10 48½			Medium = 7 35		

It appears from these experiments, that the conducting power of air to that of the Torricellian vacuum, under the circumstances described, is as $7\frac{3}{5}$ to $10\frac{48\frac{1}{2}}{60}$ inversely, or as 1000 to 702 nearly; for the quantities of heat communicated being equal,

equal, the intensity of the communication is as the times inverfely.

In thefe experiments the heat paffed through the furrounding medium *into* the bulb of the thermometer: in order to reverfe the experiment, and make the heat pafs *out* of the thermometer, I put the instruments into boiling water, and let them remain therein till they had acquired the temperature of the water, that is to fay, till the mercury in the inclofed thermometers flood at 80°; and then, taking them out of the boiling water, I plunged them fuddenly into a mixture of water and pounded ice, and moving them about continually in this mixture, I obferved the times employed in cooling as follows.

Thermometer N° 1.			Thermometer N° 2.		
Surrounded by a Torricellian vacuum.			Surrounded by air.		
Taken out of boiling water, and plunged into freezing water.			Taken out of boiling water, and plunged into freezing water.		
Time elapsed.		Heat loft.	Time elapsed.		Heat loft.
Exp. N° 7.	Exp. N° 8.		Exp. N° 9.	Exp. N° 10.	
		80°			80°
M. S.	M. S.		M. S.	M. S.	
1 2	0 54	70°	0 33	0 33	70°
0 58	1 2	60	0 39	0 34	60
1 17	1 18	50	0 44	0 44	50
1 46	1 37	40	0 55	0 55	40
2 5	2 16	30	1 17	1 18	30
3 14	3 10	20	1 57	1 57	20
5 42	5 59	10	3 44	3 40	10
Not obferved.	Not obferved.	0	40 10	Not obferved.	0
Total time of cooling from 80° to 10°.			Total time of cooling from 80° to 10°.		
M. S.			M. S.		
In Exp. N° 7. = 16 4			In Exp. N° 9. = 9 49		
In Exp. N° 8. = 16 16			In Exp. N° 10. = 9 41		
Medium = 16 10			Medium = 9 45		

By these experiments it appears, that the conducting power of air is to that of the Torricellian vacuum as $9\frac{4}{5}$ to $16\frac{1}{5}$ inverfely, or as 1000 to 603.

To determine whether the fame law would hold good when the heated thermometers, inftead of being plunged into freezing water, were fuffered to cool in the open air, I made the following experiments. The thermometers N^o 1. and N^o 2. being again heated in boiling water, as in the laft experiments, I took them out of the water, and fufpended them in the middle of a large room, where the air (which appeared to be perfectly at reft, the windows and doors being all fhut) was warm to the 16th degree of REAUMUR's thermometer, and the times of cooling were obferved as follows.

(Exp. N ^o 11.) Thermometer N ^o 1. Surrounded by a Torricellian vacuum. <i>Heated to 80°, and fufpended in the open air warm to 16°.</i>		(Exp. N ^o 12.) Thermometer N ^o 2. Surrounded by air. <i>Heated to 80°, and fufpended in the open air warm to 16°.</i>	
Time elapsed.	Heat loft.	Time elapsed.	Heat loft.
	80°		80°
M. S.		M. S.	
Not obferved.	70°	Not obferved.	70°
1 24	60	0 51	60
1 44	50	1 5	50
2 28	40	1 34	40
4 16	30	2 41	30
10 12 = total time employed in cooling from 70° to 30°.		6 11 = total time employed in cooling from 70° to 30°.	

Here the difference in the conducting powers of air and of the Torricellian vacuum appears to be nearly the fame as in the foregoing experiments, being as $6\frac{1}{5}$ to $10\frac{1}{5}$ inverfely, or as 1000 to 605. I could not obferve the time of cooling from

80° to 70°, being at that time busied in suspending the instruments.

As it might possibly be objected to the conclusions drawn from these experiments that, notwithstanding all the care that was taken in the constructing of the two instruments made use of that they should be perfectly alike, yet they might in reality be so far different, either in shape or size, as to occasion a very sensible error in the result of the experiments; to remove these doubts I made the following experiments.

In the morning towards eleven o'clock, the weather being remarkably fine, the mercury in the barometer standing at 27 inches 11 lines, REAUMUR's thermometer at 15°, and the hygrometer at 47°, I repeated the experiment N° 3. (of heating the thermometer N° 1. in boiling water, &c.) and immediately afterwards opening the cylinder containing the thermometer at its upper end, where it had been sealed, and letting the air into it, I re-sealed it hermetically, and repeated the experiment again with the same instrument, the thermometer being now surrounded with air, like the thermometer N° 2.

The result of these experiments, which may be seen in the following table, shews evidently, that the error arising from the difference of the shapes or dimensions of the two instruments in question was inconsiderable, if not totally imperceptible.

(Exp. N ^o 13.) <i>Thermometer N^o 1.</i>		(Exp. N ^o 14.) <i>The same Thermometer (N^o 1.)</i>	
Its bulb half an inch in diameter shut up in the center of a glass globe $1\frac{1}{2}$ inch in diameter, voided of air, and hermetically sealed.		The glass globe, containing the bulb of the thermometer, being now filled with air, and hermetically sealed.	
<i>Taken out of freezing water, and plunged into boiling water.</i>		<i>Taken out of freezing water, and plunged into boiling water.</i>	
Time elapsed.	Heat acquired.	Time elapsed.	Heat acquired.
	0°		0°
M. S.		M. S.	
0 55	10	0 32	10
0 55	20	0 32	20
1 7	30	0 43	30
1 15	40	0 50	40
1 29	50	1 1	50
2 2	60	1 24	60
3 21	70	2 38	70
13 44	80	10 25	80
24 48 = total time of heating from 0° to 80°.		18 5 = total time of heating from 0° to 80°.	
Total time from 0° to 70° = 11' 4".		Total time from 0° to 70° = 7' 40".	

It appears, therefore, from these experiments, that the conducting power of common atmospheric air is to that of the Torricellian vacuum as $7\frac{4}{66}$ to $11\frac{4}{66}$ inversely, or as 1000 to 602; which differs but very little from the result of all the foregoing experiments.

Notwithstanding that it appeared, from the result of these last experiments, that any difference there might possibly have been in the proportions or dimensions of the instruments N^o 1. and N^o 2. could hardly have produced any sensible error in

in the result of the experiments in question ; I was willing, however, to see how far any considerable alterations of size in the instrument would affect the experiment : I therefore provided myself with another instrument, which I shall call *Thermometer* N° 3. different from those already described in size, and a little different in its construction.

The bulb of the thermometer was of the same form and size as in the instruments N° 1. and N° 2. that is to say, it was globular, and half an inch in diameter ; but the glass globe, in the center of which it was confined, was much larger, being 3 inches $7\frac{1}{2}$ lines in diameter ; and the bore of the tube of the thermometer was much finer, and consequently its length, and the divisions of its scale, were greater. The divisions were marked upon the tube with threads of silk of different colours at every tenth degree, from 0° to 80° , as in the before-mentioned instruments. The tube or cylinder belonging to the glass globe was 8 lines in diameter, a little longer than the tube of the thermometer, and perfectly cylindrical from its upper end to its junction with the globe, being without any choak ; the thermometer being confined in the center of the globe by a different contrivance, which was as follows. To the opening of the cylinder was fitted a stopple of dry wood, covered with a coat of hard varnish, through the center or axis of which passed the end of the tube of the thermometer : this confined the tube in the axis of the cylinder at its upper end. To confine it at its lower end, there was fitted to it a small steel spring, a little below the point 0° ; which, being confined round the tube of the thermometer, had three elastic points projecting outwards, which pressing against the inside of the cylinder, confined the thermometer in its place. The total length of this instrument, from the bottom of the globe

to the upper end of the cylinder, was 18 inches, and the freezing point upon the thermometer fell about 3 inches above the bulb; consequently it lay about $1\frac{1}{2}$ inch above the junction of the cylinder with the globe, when the thermometer was confined in its place, the center of its bulb coinciding with the center of the globe. Through the stopple which closed the end of the cylinder passed two small glass tubes, about a line in diameter, which being about a line longer than the stopple were stopped up occasionally with small stopples fitted to their bores. These tubes (which were fitted exactly in the holes bored in the great stopple of the cylinder to receive them, and fixed in their places with cement) served to convey air, or any other fluid, into the glass ball, without being under a necessity of removing the stopple closing the end of the cylinder; which, in order to prevent the position of the thermometer from being easily deranged, was cemented in its place.

I have been the more particular in the description of these instruments, as I conceive it absolutely necessary to have a perfect idea of them in order to judge of the experiments made with them.

With the instrument last described (which I have called *Thermometer* N° 3.) I made the following experiment. It was upon the 18th of July last, in the afternoon, the weather variable, alternate clouds and sun-shine; wind strong at S.E. with now and then a sprinkling of rain; barometer at 27 inches $10\frac{1}{2}$ lines, thermometer at $18^{\circ}\frac{1}{4}$, and hygrometer variable from 44° to extreme moisture.

In order to compare the result of the experiment made with this thermometer with those made with the thermometer N° 2. I have, in the following table, placed these experiments by the side of each other.

(Exp.

(Exp. N° 15.) Thermometer N° 3.		(Exp. N° 4. and N° 5.) Thermometer N° 2.			
Its bulb half an inch in diameter, shut up in the center of a glass tube, 3 inches $7\frac{1}{2}$ lines in diameter, and surrounded by air.		Its bulb half an inch in diameter, shut up in the center of a glass globe, $1\frac{1}{2}$ inch in diameter, and surrounded by air.			
Taken out of freezing water, and plunged into boiling water.		Taken out of freezing water, and plunged into boiling water.			
Time elapsed.		Time elapsed.			Heat acquired.
		Exp. N° 4.	Exp. N° 5.	Medium.	
M. S.	°	M. S.	M. S.	M. S.	°
0 33	10	0 30	0 30	0 30	10
0 38	20	0 35	0 37	0 36	20
0 54	30	0 41	0 41	0 41	30
0 51	40	0 49	0 53	0 51	40
1 7	50	1 1	0 59	1 0	50
1 28	60	1 24	1 20	1 22	60
2 28	70	2 45	2 25	2 35	70
9 0	80	9 10	9 38	9 24	80
16 59 = total time of heating from 0° to 80°.		16 55	17 3	16 59 = total time of heating from 0° to 80°.	
Time from 0° to 70° = 7' 59".		Time from 0° to 70° = 7' 35"			

If the agreement of these experiments with the thermometers N° 2. and N° 3. surprised me, I was not less surprised with their disagreement in the experiment which follows.

Experiment N° 16.

Taking the thermometer N° 3. out of the boiling water, I immediately suspended it in the middle of a large room, where the air, which was quiet, had the temperature of $18\frac{1}{4}$ R. and observed the times of cooling as follows :

Time elapsed.		Heat lost.
<hr/>		80°
M.	S.	°
1	55	70°
0	12	60°
0	33	50°
2	15	40°
4	0	30°
<hr/>		

9 55 = total time of cooling from 80° to 30°.

Time from 70° to 30° = 8' 0''; but in the experiment N° 12. with the thermometer N° 2. the time employed in cooling from 70° to 30° was only 6' 11''. In this experiment, with the thermometer N° 3. the time employed in cooling from 60° to 30° was 7' 48''; but in the above-mentioned experiment, with the thermometer N° 2. it was only 5' 20''. It is true, the air of the room was somewhat cooler when the former experiment was made than when this latter was made with the thermometer N° 3.; but this difference of temperature, which was only $2^{\circ}\frac{1}{4}$ (in the former case the thermometer in the room standing at 16°, and in the latter at $18^{\circ}\frac{1}{4}$) certainly could not have occasioned the whole of the apparent difference in the results of the experiments.

Does air receive heat more readily than it parts with it? This is a question highly deserving of further investigation, and I shall not fail to give it a full examination in the course of my projected inquiries; but leaving it for the present, I shall proceed to give an account of the experiments which I have already made*.

It

* Conceiving it to be a step of considerable importance towards coming at a further

It having been my intention from the beginning to examine the conducting powers of the artificial airs or gasses, the thermometer

further knowledge of the nature of heat, to ascertain, by indisputable evidence, its passage through the Torricellian vacuum, and to determine, with as much precision as possible, the law of its motions in that medium; and being apprehensive that doubts might arise with respect to the experiments before described, on account of the contact of the tubes of the inclosed thermometers in the instruments made use of with the containing glass globes, or rather with their cylinders; by which means it might be suspected, that a certain quantity, if not all the heat acquired, might possibly be communicated: to put this matter beyond all doubt, I made the following experiment.

In the middle of a glass body, of a pear-like form, about 3 inches long, and $2\frac{1}{2}$ inches in its greatest diameter, I suspended a small mercurial thermometer, $5\frac{1}{2}$ inches long, by a fine thread of silk, in such a manner that neither the bulb of the thermometer, nor its tube, touched the containing glass body in any part. The tube of the thermometer was graduated, and marked with fine threads of silk of different colours bound round it, as in the thermometers belonging to the other instruments already described; and the thermometer was suspended in its place by means of a small steel spring, to which the end of the thread of silk which held the thermometer being attached, it (the spring) was forced into a small globular protuberance or cavity, blown in the upper extremity of the glass body, about half an inch in diameter, where the spring remaining, the thermometer necessarily remained suspended in the axis of the glass body. There was an opening at the bottom of the glass body, through which the thermometer was introduced; and a barometrical tube being soldered to this opening, the inside of the glass body was voided of air by means of mercury; and this opening being afterwards sealed hermetically, and the barometrical tube being taken away, the thermometer was left suspended in a Torricellian vacuum.

In this instrument, as the inclosed thermometer did not touch the containing glass body in any part, on the contrary, being distant from its internal surface an inch or more in every part, it is clear, that whatever heat passed *into* or *out of* the thermometer must have passed *through* the surrounding Torricellian vacuum: for it cannot be supposed, that the fine thread of silk, by which the thermometer was suspended, was capable of conducting any heat at all, or at least any sensible quantity. I therefore flattered myself with hopes of being able, with the

thermometer N^o 3. was constructed with a view to those experiments; and having now provided myself with a stock of those different kinds of airs, I began with *fixed air*, with which, by

assistance of this instrument, to determine positively with regard to the passage of heat in the Torricellian vacuum: and this, I think, I have done, notwithstanding that an unfortunate accident put it out of my power to pursue the experiments so far as I intended.

This instrument being fitted to a small stand or foot of wood, in such a manner that the glass body remained in a perpendicular situation, I placed it in my room, by the side of another inclosed thermometer (N^o 2.), which was surrounded by air, and observed the effect of the variation of heat in the atmosphere. I soon discovered, by the motion of the mercury in the inclosed thermometer, that the heat passed through the Torricellian vacuum; but it appeared plainly from the sluggishness or great insensibility of the thermometer, that the heat passed with much greater difficulty in this medium than in common air. I now plunged both the thermometers into a bucket of cold water; and I observed that the mercury in the thermometer surrounded by air descended much faster than that in the thermometer surrounded by the Torricellian vacuum. I took them out of the cold water, and plunged them into a vessel of hot water (having no conveniencies at hand to repeat the experiment in form with the freezing and with the boiling water); and the thermometer surrounded by the Torricellian vacuum appeared still to be much more insensible or sluggish than that surrounded by air.

These trials were quite sufficient to convince me of the passage of heat in the Torricellian vacuum, and also of the greater difficulty of its passage in that medium than in common air; but, not satisfied to rest my inquiries here, I took the first opportunity that offered, and set myself to repeat the experiments which I had before made with the instruments N^o 1. and N^o 2. I plunged this instrument into freezing water, where I let it remain till the mercury in the inclosed thermometer had descended to 0°; when, taking it out of the freezing water, I plunged it suddenly into a vessel of boiling water, and prepared myself to observe the ascent of the mercury in the inclosed thermometer as in the foregoing experiments; but unfortunately the moment the end of the glass body touched the boiling water, it cracked with the heat at the point where it had been hermetically sealed, and the water rushing into the body, spoiled the experiment: and I have not since had an opportunity of providing myself with another instrument to repeat it.

means-

means of water, I filled the globe and cylinder containing the thermometer; and stopping up the two holes in the great stopple closing the end of the cylinder, I exposed the instrument in freezing water till the mercury in the inclosed thermometer had descended to 0° ; when, taking it out of the freezing water, I plunged it into a large vessel of boiling water, and prepared myself to observe the times of heating, as in the former cases; but an accident happened, which suddenly put a stop to the experiment. Immediately upon plunging the instrument into the boiling water, the mercury began to rise in the thermometer with such uncommon celerity, that it had passed the first division upon the tube (which marked the 10th degree, according to REAUMUR's scale) before I was aware of its being yet in motion; and having thus missed the opportunity of observing the time elapsed when the mercury arrived at that point, I was preparing to observe its passage of the next, when all of a sudden the stopple closing the end of the cylinder was blown up the chimney with a great explosion, and the thermometer, which, being cemented to it by its tube, was taken along with it, and was broken to pieces, and destroyed in its fall.

This unfortunate experiment, though it put a stop for the time to the inquiries proposed, opened the way to other researches not less interesting. Suspecting that the explosion was occasioned by the rarefaction of the water which remained attached to the inside of the globe and cylinder after the operation of filling them with fixed air; and thinking it more than probable, that the uncommon celerity, with which the mercury rose in the thermometer, was principally owing to the same cause; I was led to examine the conducting power of *moist air*, or air saturated with water.

For this experiment I provided myself with a new thermometer N° 4. the bulb of which, being of the same form as those already described (*viz.* globular) was also of the same size, or half an inch in diameter. To receive this thermometer a glass cylinder was provided, 8 lines in diameter, and about 14 inches long, and terminated at one end by a globe $1\frac{1}{2}$ inch in diameter. In the center of this globe the bulb of the thermometer was confined, by means of the stopple which closed the end of the cylinder; which stopple, being near 2 inches long, received the end of the tube of the thermometer into a hole bored through its center or axis, and confined the thermometer in its place, without the assistance of any other apparatus. Through this stopple two other small holes were bored, and lined with thin glass tubes, as in the thermometer N° 3. opening a passage into the cylinder, which holes were occasionally stopped up with some stopples of cork; but to prevent accidents, such as I had before experienced from an explosion, great care was taken not to press these stopples into their places with any considerable force, that they might the more easily be blown out by any considerable effort of the confined air.

Though in this instrument the thermometer was not altogether so steady in its place as in the thermometers N° 1. N° 2. and N° 3. the elasticity of the tube, and the weight of the mercury in the bulb of the thermometer, occasioning a small vibration or trembling of the thermometer upon any sudden motion or jar; yet I preferred this method to the others, on account of the lower part of this thermometer being intirely free, or suspended in such a manner as not to touch, or have any communication with, the lower part of the cylinder or the globe: for though the quantity of heat received by the tube of the thermometer at its contact with the cylinder at its
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choaks, in the instruments N° 1. and N° 2. or with the branches of the steel spring in N° 3. and from thence communicated to the bulb, must have been exceedingly small; yet I was desirous to prevent even that, and every other possible error or inaccuracy, however small, that might arise.

Does humidity augment the conducting power of air?

To determine this question I made the following experiments, the weather being clear and fine, the mercury in the barometer standing at 27 inches 8 lines, the thermometer at 19°, and the hygrometer at 44°.

(Exp. N° 17.) Thermometer N° 4. Surrounded by air <i>dry</i> to the 44th degree of the quill hy- grometer of the Manheim Academy. <i>Taken out of freezing water, and plunged into boiling water.</i>		(Exp. N° 18.) The same thermometer (N° 4.) Surrounded by air rendered as <i>moist</i> as possible by wetting the inside of the cylinder and globe with water. <i>Taken out of freezing water, and plunged into boiling water.</i>	
Time elapsed.	Heat acquired.	Time elapsed.	Heat acquired.
	80°		0°
M. S.		M. S.	
0 34	10°	0 6	10°
0 39	20°	0 4	20°
0 44	30°	0 5	30°
0 51	40°	0 9	40°
1 6	50°	0 18	50°
1 35	60°	0 26	60°
2 40	70°	0 43	70°
not observed.	80°	7 45	80°
8 9 = total time of heating from 0° to 70°.		1 51 = total time of heating from 0° to 70°	

From these experiments it appears, that the conducting power of air is very much increased by humidity. To see if the same result would obtain when the experiment was reversed, I now took the thermometer with the *moist* air out of the boiling water, and plunged it into freezing water; and moving it about continually from place to place in the freezing water, I observed the times of cooling, as set down in the following table. N. B. To compare the result of this experiment with those made with *dry* air, I have placed on one side in the following table the experiment in question, and on the other side the experiment N^o 19. made with the thermometer N^o 2.

(Exp. N ^o 19.) Thermometer N ^o 4. Surrounded by <i>moist</i> air. Taken out of boiling water, and plunged into freezing water.			(Exp. N ^o 10.) Thermometer N ^o 2. Surrounded by <i>dry</i> air. Taken out of boiling water, and plunged into freezing water.		
Time elapsed.		Heat lost.	Time elapsed.		Heat lost.
		80°			80°
M.	S.		M.	S.	
0	4	70	0	33	70
0	14	60	0	34	60
0	31	50	0	44	50
0	52	40	0	55	40
1	22	30	1	18	30
2	3	20	1	57	20
4	2	10	3	40	10
9 8 = total time of cooling from 80° to 10°.			9 12 = total time of cooling from 80° to 10°.		

Though the difference of the whole times of cooling from 80° to 10° in these two experiments appears to have been very small,

small, yet the difference of the times taken up by the first twenty or thirty degrees from the boiling point is very remarkable, and shows with how much greater facility heat passes in moist air than in dry air. Even the slowness with which the mercury in the thermometer N^o 4. descended in this experiment from the 30th to the 20th, and from the 20th to the 10th degree, I attribute in some measure to the great conducting power of the moist air with which it was surrounded; for the cylinder containing the thermometer and the moist air, being not wholly submerged in the freezing water, that part of it which remained out of the water was necessarily surrounded by the air of the atmosphere; which being much warmer than the water, communicated of its heat to the glass; which, passing from thence into the contained moist air as soon as that air became colder than the external air, was, through that medium, communicated to the bulb of the inclosed thermometer, which prevented its cooling so fast as it would otherwise have done. But when the weather becomes cold, I propose to repeat this experiment with variations, in such a manner as to put the matter beyond all doubt. In the mean time I cannot help observing, with what infinite wisdom and goodness Divine Providence appears to have guarded us against the evil effects of excessive heat and cold in the atmosphere; for if it were possible for the air to be equally damp during the severe cold of the winter months as it sometimes is in summer, its conducting power, and consequently its apparent coldness, when applied to our bodies, would be so much increased, by such an additional degree of moisture, that it would become quite intolerable; but, happily for us, its power to hold water in solution is diminished, and with it its power to rob us of our animal heat, in proportion as its

coldness is increased. Every body knows how very disagreeable a very moderate degree of cold is when the air is very damp; and from hence it appears, why the thermometer is not always a just measure of the apparent or sensible heat of the atmosphere. If colds or catarrhs are occasioned by our bodies being robbed of our animal heat, the reason is plain why those disorders prevail most during the cold autumnal rains, and upon the breaking up of the frost in the spring. It is likewise plain from whence it is that sleeping in damp beds, and inhabiting damp houses, is so very dangerous; and why the evening air is so pernicious in summer and in autumn, and why it is not so during the hard frosts of winter. It has puzzled many very able philosophers and physicians to account for the manner in which the extraordinary degree or rather *quantity* of heat is generated which an animal body is supposed to lose, when exposed to the cold of winter, above what it communicates to the surrounding atmosphere in warm summer weather; but is it not more than probable, that the difference of the quantities of heat, actually lost or communicated, is infinitely less than what they have imagined? These inquiries are certainly very interesting; and they are undoubtedly within the reach of well contrived and well conducted experiments. But taking my leave for the present of this curious subject of investigation, I hasten to the sequel of my experiments.

Finding so great a difference in the conducting powers of common air and of the Torricellian vacuum, I was led to examine the conducting powers of common air of different degrees of density. For this experiment I prepared the thermometer N^o 4. by stopping up one of the small glass tubes passing through the stopple, and opening a passage into the cylinder, and by fitting a valve to the external overture of the
other,

other. The instrument, thus prepared, being put under the receiver of an air-pump, the air passed freely out of the globe and cylinder upon working the machine, but the valve above described prevented its return upon letting air into the receiver. The gage of the air-pump showed the degree of rarity of the air under the receiver, and consequently of that filling the globe and cylinder, and immediately surrounding the thermometer.

With this instrument, the weather being clear and fine, the mercury in the barometer standing at 27 inches 9 lines, the thermometer at 15° , and the hygrometer at 47° , I made the following experiments.

(Exp. N ^o 20.) <i>Thermometer N^o 4.</i> Surrounded by common air, barometer standing at 27 inches 9 lines. <i>Taken out of freezing water, and plunged into boiling water.</i>		(Exp. N ^o 21.) <i>Thermometer N^o 4.</i> Surrounded by air rarefied by pumping till the barometer-gage stood at 6 inches $11\frac{1}{2}$ lines. <i>Taken out of freezing water, and plunged into boiling water.</i>		(Exp. N ^o 22.) <i>Thermometer N^o 4.</i> Surrounded by air rarefied by pumping till the barometer-gage stood at 1 inch 2 lines. <i>Taken out of freezing water, and plunged into boiling water.</i>	
Time elapsed.	Heat acquired. 0°	Time elapsed.	Heat acquired. 0°	Time elapsed.	Heat acquired. 0°
M. S.	0	M. S.	0	M. S.	0
0 31	10	0 31	10	0 29	10
0 40	20	0 38	20	0 36	20
0 41	30	0 44	30	0 49	30
0 47	40	0 51	40	1 1	40
1 4	50	1 7	50	1 1	50
1 25	60	1 19	60	1 24	60
2 28	70	2 27	70	2 31	70
10 17	80	10 21	80	not observed.	80
7 36 = total time of heating from 0° to 70°.		7 37 = total time of heating from 0° to 70°.		7 51 = total time of heating from 0° to 70°.	

The result of these experiments, I confess, surpris'd me not a little; but the discovery of truth being the sole object of my inquiries (having no favourite theory to defend) it brings no disappointment along with it, under whatever unexpected shape it may appear. I hope that further experiments may lead to the discovery of the cause why there is so little difference in the conducting powers of air of such very different degrees of rarity, while there is so great a difference in the conducting powers of air, and of the Torricellian vacuum. At present, I shall not venture any conjectures upon the subject; but in the mean time I dare to assert, that the experiments I have made may be depended on.

The time of my stay at Manheim being expired (having had the honour to attend thither his most Serene Highness the Elector Palatine Duke of Bavaria, my most Gracious Master, in his late journey), I was prevented from pursuing these inquiries further at that time; but I shall not fail to recommence them the first leisure time I can find, which I fancy will be about the beginning of the month of November. In the mean time, to enable myself to pursue them with effect, I am sparing neither labour nor expence to provide a complete apparatus necessary for my purpose; and his Electoral Highness has been graciously pleased to order M. ARTARIA (who is in his service) to come to Munich to assist me. With such a Patron as his most Serene Highness, and with such an assistant as ARTARIA, I shall go on in my pursuits with cheerfulness. Would to God that my labours might be as useful to others as they will be pleasant to me!

I shall conclude this letter with a short account of some experiments I have made to determine the conducting powers

of water and of mercury; and with a table, showing at one view the conducting powers of all the different mediums which I have examined.

Having filled the glass globe inclosing the bulb of the thermometer N° 4. first with water, and then with mercury, I made the following experiments, to ascertain the conducting powers of those two fluids.

(Exp. N° 23.) Thermometer N° 4. Surrounded by water. Taken out of freezing water, and plunged into boiling water.		(Exp. N° 24, 25, and 26.) Thermometer N° 4. Surrounded by mercury. Taken out of freezing water, and plunged into boiling water.			
Time elapsed. Heat acquired.		Time elapsed.			Heat acquired.
		Exp. N° 24.	Exp. N° 25.	Exp. N° 26.	
M. S.	°	M. S.	M. S.	M. S.	°
0 19	10	0 5	0 5	0 5	10
0 8	20	0 4	0 2	0 5	20
0 9	30	0 2	0 2	0 4	30
0 11	40	0 4	0 5	0 5	40
0 15	50	0 4	0 4	0 7	50
0 21	60	0 7	0 4	0 8	60
0 34	70	0 15	0 9	0 14	70
2 13	80	Not observed.	0 58	Not observed.	80
1 57 = total time of heating from 0° to 70°.		0 41	0 31	0 48 = total times of heating from 0° to 70°.	

The total times of heating from 0° to 70° in the three experiments with mercury being 41 seconds, 31 seconds, and 48 seconds, the mean of these times is $36\frac{2}{3}$ seconds; and as in the experiment with water the time employed in acquiring the same degree of heat was 1' 57" = 117 seconds, it appears from

from these experiments, that the conducting power of mercury to that of water, under the circumstances described, is as $36\frac{2}{3}$ to 117 inversely, or as 1000 to 313. And hence it is plain, why mercury *appears* so much hotter, and so much colder, to the touch than water, when in fact it is of the same temperature: for the force or violence of the sensation of *hot* or *cold* depends not intirely upon the temperature of the body exciting in us those sensations, or upon the degree of heat it actually possesses, but upon the *quantity* of heat it is capable of communicating to us, or receiving from us, in any given short period of time, or as the intensity of the communication; and this depends in a great measure upon the conducting powers of the bodies in question.

The sensation of *hot* is the entrance of heat into our bodies; that of *cold* is its exit; and whatever contributes to facilitate or accelerate this communication adds to the violence of the sensation. And this is another proof that the thermometer cannot be a just measure of the *sensible* heat, or cold, existing in bodies; or rather, that the touch does not afford us a just indication of their *real* temperatures.

Fig. 1.

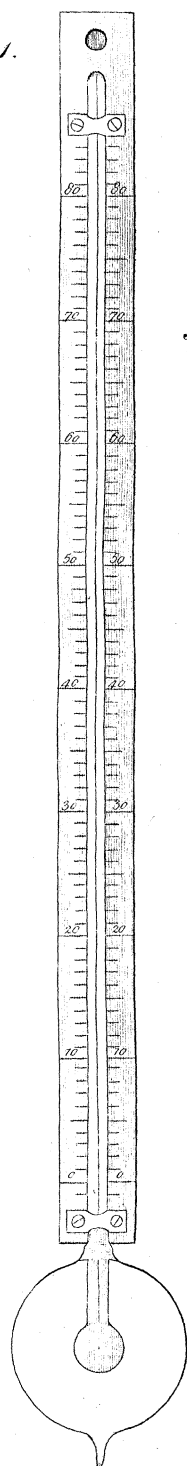


Fig. 2.

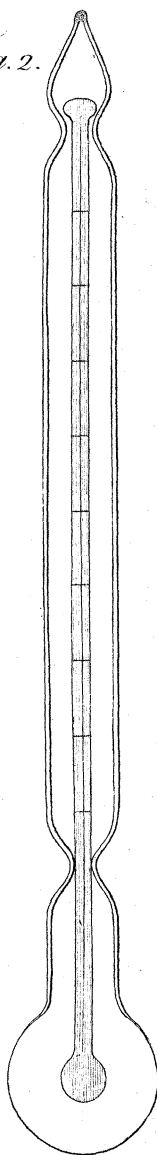


Fig. 3.

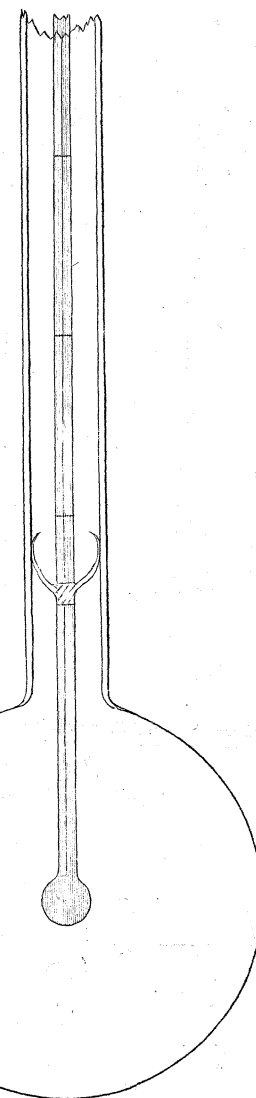
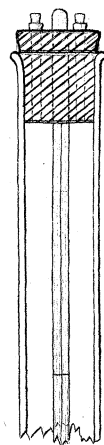
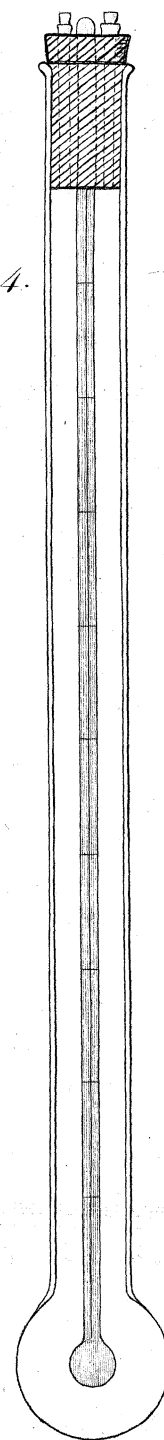


Fig. 4.



Scale $\frac{1}{2}$ an Inch to the Inch.

A Table of the conducting Powers of the under-mentioned Mediums, as determined by the foregoing experiments.

Thermom. N ^o 1.		Thermometer N ^o 4.					
<i>Taken out of freezing water, and plunged into boiling water.</i>							
Time elapsed.							
Toricellian Va- cuum (Exp. N ^o 3. 4. and 13.)	Common air, density = 1, (Exp. N ^o 20.)	Rarefied air, density = $\frac{1}{4}$ (Exp. N ^o 21.)	Rarefied air, density = $\frac{1}{24}$ (Exp. N ^o 22.)	Moist air (Exp. N ^o 18.)	Water (Exp. N ^o 23.)	Mercury (Exp. N ^o 24, 25, and 26.)	Heat acquired.
— M. S.	— M. S.	— M. S.	— M. S.	— M. S.	— M. S.	— M. S.	°
0 52	0 31	0 31	0 29	0 6	0 19	0 5	10
0 58	0 40	0 38	0 36	0 4	0 8	0 3 $\frac{2}{3}$	20
1 3	0 41	0 44	0 49	0 5	0 9	0 2 $\frac{2}{3}$	30
1 18	0 47	0 51	1 1	0 9	0 11	0 4 $\frac{2}{3}$	40
1 25	1 4	1 7	1 1	0 18	0 15	0 5 $\frac{1}{3}$	50
1 58	1 25	1 19	1 24	0 26	0 21	0 6 $\frac{1}{3}$	60
3 19	2 28	2 27	2 31	0 43	0 34	0 12 $\frac{2}{3}$	70
11 57	10 17	10 21	—	7 45	2 13	0 58	80
10 53	7 36	7 37	7 51	1 51	1 57	0 36 $\frac{2}{3}$	= to- tal times of heating from 0° to 70°.

In determining the relative conducting powers of these mediums, I have compared the times of the heating of the thermometers from 0° to 70° instead of taking the whole times from 0° to 80°, on account of the small variation in the heat of the boiling water arising from the variation of the weight of the atmosphere, and also on account of the very slow motion of the mercury between the 70th and the 80th degrees, and the difficulty of determining the precise moment when the mercury arrives at the 80th degree.

Taking

Taking now the conducting power of mercury = 1000, the conducting powers of the other mediums, as determined by these experiments, will be as follows, *viz.*

Mercury	. . .	1000
Moist air	. . .	330
Water,	. . .	313
Common air, density = 1		$80\frac{4}{100}$
Rarefied air, density = $\frac{1}{4}$.	$80\frac{2}{100}$
Rarefied air, density = $\frac{1}{24}$		78
The Torricellian vacuum		55

And in these proportions are the quantities of heat which these different mediums are capable of transmitting in any given time; and consequently these numbers express the relative *sensible* temperatures of the mediums, as well as their conducting powers. How far these decisions will hold good under a variation of circumstances experiment only can determine. This is certainly a subject of investigation not less curious in itself than it is interesting to mankind; and I wish that what I have done may induce others to turn their attention to this long neglected field of experimental inquiry. For my own part, I am determined not to quit it.

In the future prosecution of these inquiries, I do not mean to confine myself solely to the determining of the conducting powers of fluids; on the contrary, solids, and particularly such bodies as are made use of for cloathing, will be principal subjects of my future experiments. I have indeed already begun these researches, and have made some progress in them; but I forbear to anticipate a matter which I propose for the subject of a future communication.

